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ENHANCEMENT OF SURFACE INTEGRITY USING SPARK ASSISTED ABRASIVE FLOW MACHINING PROCESS

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ABSTRACT

In today's competitive environment components having high dimensional accuracy and better functional performance are highly demanded. Abrasive Flow Machining is one of the vital non-conventional techniques used for the finishing of complex geometries which is not easy with other conventional processes. It provides finishing up to nano level. During the finishing, parameters affecting the system efficiency are very important to identify to improve the productivity of the system. This paper discusses a newly developed technique i.e spark assisted Abrasive Flow machining, which uses the spark energy to improve the material removal and providing better surface finish and also parameters such as rotational speed of the electrode, duty cycle and current were optimized for the better surface finish using Taguchi L_9 OA.

KEYWORDS: Finishing, Spark, Hybrid, Current, Duty Cycle & Rotation

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Original Article

INTRODUCTION

Abrasive Flow Machining (AFM) is a nonconventional technique used for the finishing of complicated shapes which cannot be obtained by conventional techniques. However, in recent past, many traditional processes such as honing, lapping and broaching were used for finishing. But these processes cannot provide nano level finishing. AFM is a technique that uses a non-Newtonian media (combination of polymer, gel and abrasive) and is forced to flow through the restrictive path at a huge pressure. The advantage of using this media is that it can flow to any unreachable area which is not possible using traditional techniques [1, 2]. This process can be used to finish the burrs, edges, recast layers [3]. The disadvantage of this process is low material removal. So various researchers hybridize this process with other techniques to get better material removal. Kenda et al. [4] used AFM process for finishing the profile of plastic gear and found an increase in the life cycle of the gear with a significant decrease in the finishing cost. Subramanian et al. [5] finished hip joint of Co-Cr alloy using AFM process in the biomedical area and found minimum surface roughness of 39 nm. Sidpara et al. [6] studied the rheological behavior of the MR fluid in the presence of a magnetic field. Sambharia and Mali [7-9] developed a new media based on polymer abrasive gel and identified the effect of parameters such as abrasive concentration, abrasive mesh size, media temperature, an additive percentage on the viscosity of media. Judal and Yadava [10] combined ECM process with Magnetic assisted AFM to finish non-magnetic stainless steel and analyze the effect of parameters such as magnetic flux density, rotational speed and current on the material removal and surface roughness.

METHODS

Although Abrasive Flow Machining process provides a good level of finishing it has a constraint of low material removal. Many researchers have hybridized this process with other nonconventional techniques to improve its material removal. This paper discusses a newly developed technique which uses the spark energy to melt the surface material so that the abrasives can easily take away the softened material. This process uses a power supply system which converts the AC supply to the pulsed DC supply. The positive supply was given to the workpiece while negative supply was given to the electrode inside the hollow cavity. When the supply is given to both the poles electrons start generating between both the poles and start moving to the opposite polarity. This movement of ions can be seen as a spark which melted the surface material. The experimental setup of the developed hybrid process is shown in figure 1.

Figure 1: Experimental Setup of Developed Hybrid Abrasive Flow Machining Process

The experimental setup included a fixture for holding the workpiece and guiding the media from one media cylinder to the other, power supply system, gears for the rotation of electrode to maintain the uniformity of surface, bearings. The rotation of either workpiece or electrode is necessary to maintain the uniformity of the surface otherwise spark will melt the surface at a particular spot and damages the surface integrity of the surface.

PERCENTAGE IMPROVEMENT IN SURFACE ROUGHNESS

To analyze the effect of variable parameters on the response i.e percentage improvement in surface roughness, experiments were planned and analyzed using Taguchi L_9 Orthogonal array. Percentage improvement in surface roughness can be calculated by the equation given below-

% improvement in R_a = (Initial Roughness - Final Roughness)/(Initial Roughness) * 100

The present L_9 OA has three parameters with three levels of each. It has 8 degrees of freedom. Brass was taken as the workpiece having a hollow cylindrical shape of an outer diameter of 10 mm and an inner diameter of 8 mm with a length of 16 mm. The variable parameters with their levels affecting the performance of the system are noted in Table 1.

Table 1: Process Parameters and their Values at Different Levels

Symbol	Parameters	Unit	L_1	L_2	L_3
S	Rotational speed	RPM	150	200	250
D	Duty Cycle	Fraction	0.68	0.73	0.78
I	Current	Ampere	3	6	9
Polymer to Gel Ratio: 1:1, **Workpiece Material:** Brass, **Abrasive Type:** Al_2O_3, **Initial Surface Roughness:** 1.1 - 2.85 microns					

Experiments were performed according to the L_9 OA. A number of 9 experiments were performed with three times each, which means a total 27 experiments were performed to analyze the behavior of the parameters as given in Table 1. The initial surface roughness of the workpiece was in the range of 1.1-2.85 micron. For every sample operation and its replications, % Δ R_a was measured and recorded in Table 2.

Table 2: Experimental Results of Percentage Improvement in Surface Roughness as per TAGUCHI L_9 OA

E.N	Run Order	% Improvement in Ra			S/N Ratio
		R_1	R_2	R_3	
1	1	7.25	8.34	8.79	18.11
2	4	16.1	17.1	19.24	24.78
3	7	15.5	16.85	15.6	24.05
4	2	16.42	17.95	17.23	24.69
5	5	29.08	31.92	32.12	29.81
6	8	20.84	23.74	28.295	27.5
7	3	9.58	10.52	10.93	20.25
8	6	13.94	14.87	13.31	22.92
9	9	14.68	14.27	15.76	23.44
Total		**143.39**	**155.56**	**161.275**	
		T ΔRa = Overall mean of ΔRa=17.04%			

RESULTS AND DISCUSSIONS

Surface roughness was measured through the Taylor Hobson precision machine having the resolution of 0.01 micrometer. The percentage improved R_a value for each trial condition is shown in Table 2. Higher the better quality characteristic was taken for the response and for calculating the S/N ratio as given in equation 1.

$$(S/N)_{HB} = -10 \log\left[\frac{1}{n} \sum_{j=1}^{R} \frac{1}{Y_j^2}\right] \quad (1)$$

Figure 2 shows, on increasing the rotational speed percentage improvement in surface finish increased up to 200 rpm and further decreased on increasing the rotational speed. As the rotational speed was increased it forced the abrasive particles towards the surface with a larger force due to the developed centrifugal force which corresponded more material removal and greater surface finish, but further increasing the rotational speed increased the media temperature and caused restriction during the media flow. This reduced the media viscosity which corresponded decrease in viscosity of media due to which abrasive particles did not participate in the abrasion process which reduced the percentage improvement in the surface roughness.

Figure 3 shows surface finish got better on increasing the duty cycle up to 0.73 but decreased after a further increase in duty cycle. Duty cycle means the frequency of spark in the gap. As duty cycle increases, the discharge energy will be available for a larger duration which developed high temperature on the surface and abrasive particles easily took away the melted material. However, on further increasing the duty cycle produced a larger crater on the surface and

degrades the surface quality.

Figure 4 shows the effect of current on the surface finish of the product. As the value of current was increased larger discharge energy was available for melting the surface material, which made easy for the abrasive particles to take away the softened material and corresponded better surface finish.

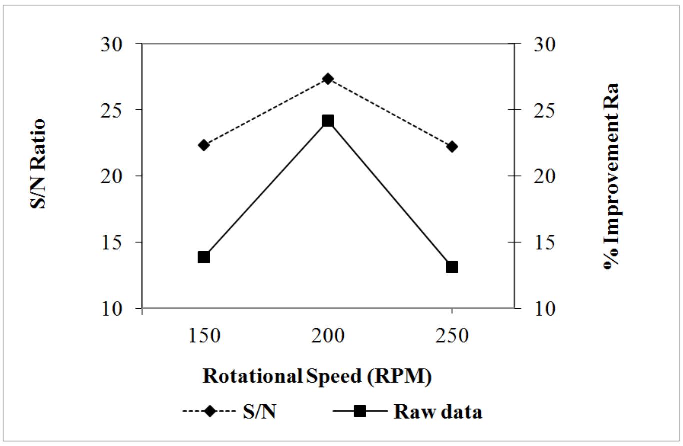

Figure 2: Effect of Rotational Speed on the S/N Ratio and % ΔR_a

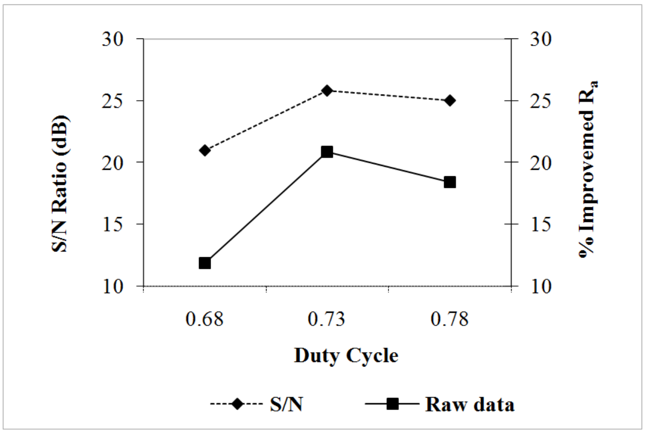

Figure 3: Effect of Duty Cycle on the S/N Ratio and % ΔRa

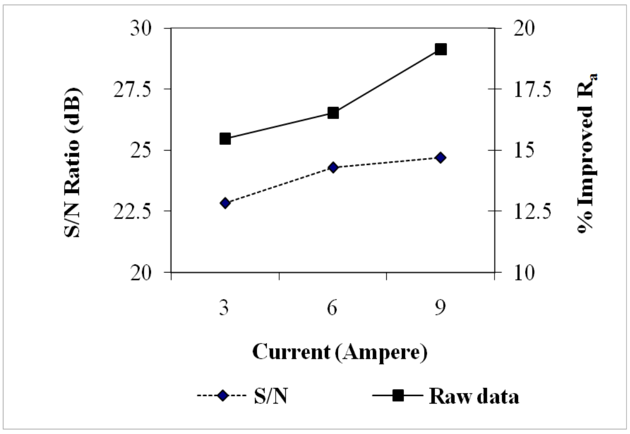

Figure 4: Effect of Current on the S/N Ratio and % ΔR_a

Table 3 shows the average value and main effect for the % Δ R_a.

Table 3: Main Effects of % Δ R_a

Process Parameter	Level	Rotational Speed (S)		Duty Cycle (D)		Current (I)	
Type of Data		Raw Data	S/N Ratio	Raw Data	S/N Ratio	Raw Data	S/N Ratio
Average Values(%Ra)	L_1	13.86	22.31	11.89	21.01	15.48	22.84
	L_2	24.17	27.33	20.85	25.83	16.52	24.3
	L_3	13.09	22.2	18.39	25	19.12	24.7
Main Effects(%Ra)	L_2-L_1	10.31	5.02	8.96	4.81	1.04	1.45
	L_3-L_2	-11.08	-5.13	-2.46	-0.83	2.59	0.4
Difference (L_3-L_2)–(L_2-L_1)		-21.39	-10.15	-11.42	-5.65	1.55	-1.05
L_1, L_2, L_3 shows levels of parameters.							

In this analysis, ANOVA technique was used to analyze the effect of variables on the response, i.e % ΔR_a. Table 4 and Table 5 represent the ANOVA for the raw data and S/N data. It can be observed from the Tables that the parameters affect the mean and variability in the R_a value.

Table 4: Pooled value of ANOVA for Raw Data (ΔR_a)

Source	SS	DOF	V	F-Ratio	SS'	P%
Rotational Speed	689.3	2	344.65	97.11	682.2	56.99
Duty Cycle	386.04	2	193.02	54.38	378.94	31.91
Current	63.11	2	31.55	8.89	56.01	5.21
E	70.98	20	3.54	------	92.27	5.86
Total (T)	**1209.44**	**26**	*	-------	**1209.44**	**100**
Fcritical =3.4928 (Tabulated Value)						

Table 5: Pooled ANOVA (S/N Data)(ΔR_a)

Source	SS	DOF	V	F-Ratio	SS'	P%
Rotational Speed	51.56	2	25.78	207.87	51.31	52.97
Duty Cycle	39.77	2	19.88	160.33	39.52	40.86
Current	5.74	2	2.87	23.17	5.50	5.90
e	0.24	2	0.12	------	0.99	0.25
Total (T)	**97.33**	**8**	--------	-------	**97.33**	**100**
F critical = 19(Tabulated Value)						

The optimum $\%\Delta R_a$ was determined and related confidence intervals were predicted.

For the mean of $\%\Delta R_a$, optimum condition for the response is estimated as:

$\mu = \bar{S}_2 + \bar{D}_2 + \bar{I}_3 - 2\bar{T}$ (1)

$\bar{T}$ = overall mean of the R_a obtained = 17.04 %

$\bar{S}_2$ = Average value of % age improvement in R_a at the 2^{nd} level of rotational speed = 24.17%

$\bar{D}_2$ = Average value of % age improvement in R_a at the 2^{nd} level of duty cycle = 20.85 %

$\bar{I}_3$ = Average value of % age improvement in R_a at the 3^{rd} level of Current =19.12 %

Substituting these values, % improvement in R_a = 30.06 %

(CL_{CE}) and (CL_{POP}) can be calculated by using the equations (2) & (3):

$CI_{CE} = \sqrt{F_a (1, f_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$ (2)

$CI_{POP} = \sqrt{[F_a(1, f_e)\ V_e]/ [n_{eff}\ ]}$ (3)

Where CI_{CE} = Confidence interval for confirmation experiments

CI_{POP} = Confidence interval for population

$F_\alpha\,(1, f_e)$ = The F- ratio having confidence level of $(1\text{-}\alpha)$

f_e =3.49 (Value Tabulated)

f_e = Error Degree Of Freedom = 20

N= Total number of experiments =27

R = Size of Sample = 3

V_e = Error variance = 3.55

By using equation no. (4), one may achieve

n_{eff} = 3.86

So, $CI_{CE} = \pm\ 2.70$

and $CI_{POP} = \pm\ 1.79$

The Confirmation interval for predicted response is:

27.36< %age improvement in ΔR_a <32.76

The 95% confirmation interval of predicted mean is

28.27<%age improvement in ΔR_a <31.85

The optimum level of the parameters for percentage %Δ R_a is $S_2D_2I_3$.

S_2 = Rotational speed at second level =200 RPM

D_2 = Duty Cycle at second level = 0.73

I_3 = Current at Third level =9 Ampere

The results are presented in Table 6 for % improved R_a.

Percentage improved R_a from the confirmation experiments are inside the specified range.

The mean values of percentage improved R_a and S/N ratio for every parameter at all the levels was calculated and given in Table 6.

Table 6: Values Obtained from Confirmation Experiments

Response	Optimum Condition	Predicted Response	Confidence Intervals 95%	Real Value
%Improvement ΔR_a	$S_2D_2I_3$	30.06 %	CI_{CE}:27.36<%ΔR_a<32.76 CI_{POP}:28.27<%ΔR_a<31.85	27.75 %

SEM ANALYSIS

As the power supply is provided between both poles, a spark is generated in the gap. This developed high temperature on the surface and caused oxide layer formation on the surface. The surface materials started melting and became soft. The melting of the surface can be easily studied by figure 5, which clearly shows the spots developed by the spark on the surface.

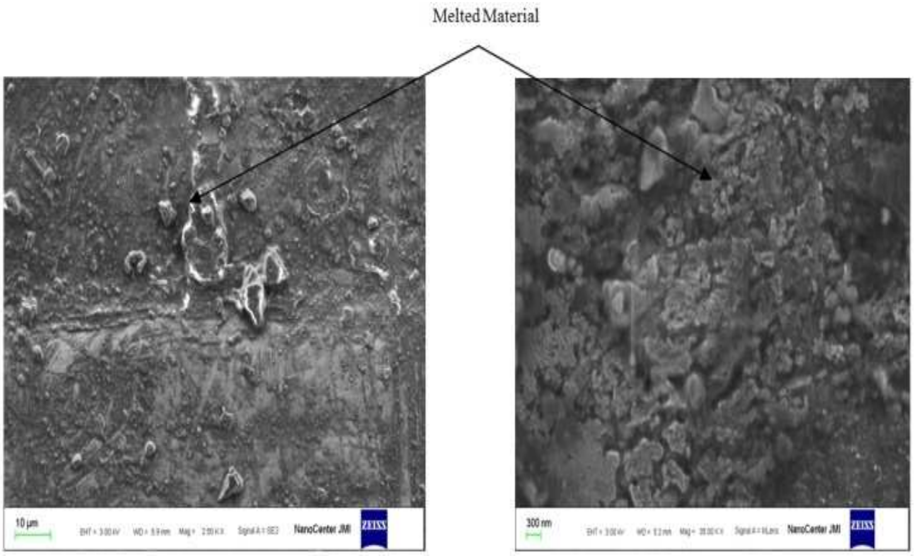

Figure 5: SEM Images of Surface During Finishing

XRD ANALYSIS

X- ray diffraction technique for the finished surface was analyzed by using “X’ Pert High Score” software. XRD of the brass workpiece after finishing can be observed from figure 6. The figure confirms the formation of Copper vanadium fluoride oxide at the plane (004) for a diffraction angle of 49.48 degrees [Ref- 00-043-0082], and formation of Copper magnesium oxide at the plane (4400) for a diffraction angle of 43.418 degrees [Ref- 01-074-1921]. Copper Praseodymium oxide was formed at a plane (105) with a diffraction angle of 43.47 degrees [Ref- 00-049-1891].

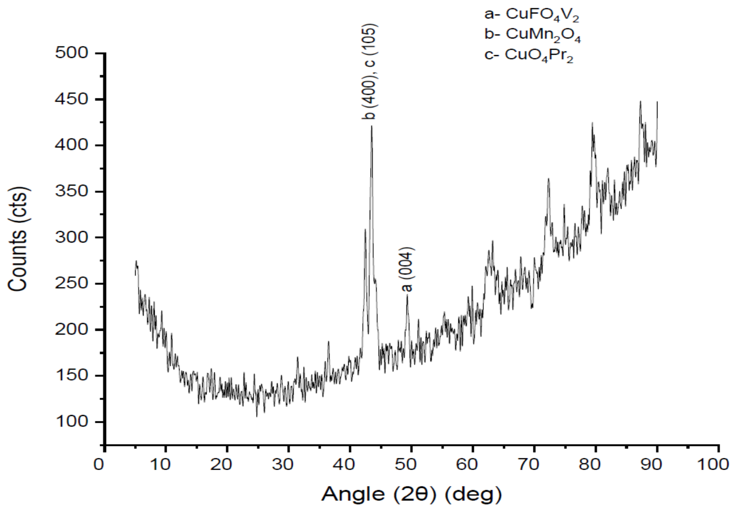

Figure 6: XRD Graph of the Finished Brass Workpiece

CONCLUSIONS

The following conclusions can be drawn on the basis of the above experimental study-

- The experimental results show that rotational speed is contributing 56.99 %, a duty cycle is contributing 31.91% and current is contributing 5.21 % towards percentage improvement in surface roughness.
- The 95% confidence interval of the % Δ R_a is $27.36 < \%\Delta R_a < 32.76$.
- The experimental results show optimum result at the second level of rotation speed (200 rpm), a second level of the duty cycle (0.73) and third level of current (9 Ampere).
- Melted material observed by the SEM image shows less requirement of abrasion force for removing the material.
- The XRD results confirm the oxide formation on the surface of the materials.

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